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Wireless E911 Location Accuracy Requirements	Docket No. 07-114
E911 Requirements for IP-Enabled Service Providers	WC Docket No. 05-196

Comments of Yi Zhang, Andrea Forte and Henning Schulzrinne

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Measuring GPS Position Accuracy in Mobile Devices

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Abstract

We aim to test accuracy and time to first fix of GPS devices. We focus on mobile devices like the Android HTC Dream/G1 and the iPod touch in a variety of settings including open sky, heavy foliage and urban canyon. Accuracy and time to first fix vary significantly in different settings and can be influenced by many factors. Based on our measures, location accuracy can be expected to be within approximately 2 meters of the real position in an open sky setting, 8 meters in a heavy foliage setting, and 12 meters in an urban canyon setting.

1 Introduction

"The Global Positioning System (GPS) is a space-based global navigation system (GNSS) that provides reliable location and time information where there is an unobstructed line of sight to four or more GPS satellites" [1]. In the United States it is maintained by the United States government and is freely accessible by anyone with a GPS receiver. Nowadays consumer-grade GPS receivers, especially in cell-phones, are becoming more and more popular. At the same time location accuracy is a major concern for such devices. Generally the acquired location should be within 20 meters of the real position [2]. In reality, accuracy varies under different conditions. We tested the Android HTC Dream to determine average positional errors and time to first fix, respectively. We used several locations to represent three distinct settings including open sky (there is no tall building in the open sky setting), heavy foliage (there are only some trees in this setting) and urban canyon (this setting is surrounded by tall buildings which obstruct the view of sky so that the devices can see fewer satellites). In addition, we collected 540 measurements at noon when the weather was sunny, cloudy and in the evening with a clear sky. We compared each measurement to known locations to ascertain positional errors and distributions of position points.

Our project plan included four steps: we searched for information regarding market share of chipsets and what GPS chipsets are embedded in which devices this is important as we wanted to focus on mainstream GPS chipsets and devices; We developed an application for taking measurements on the Android-based phone and on the iPod touch; finally we took measurements in different settings and later processed and analyzed the data collected.

*The comments are the personal comments of the individuals and do not necessarily reflect the position of Columbia University

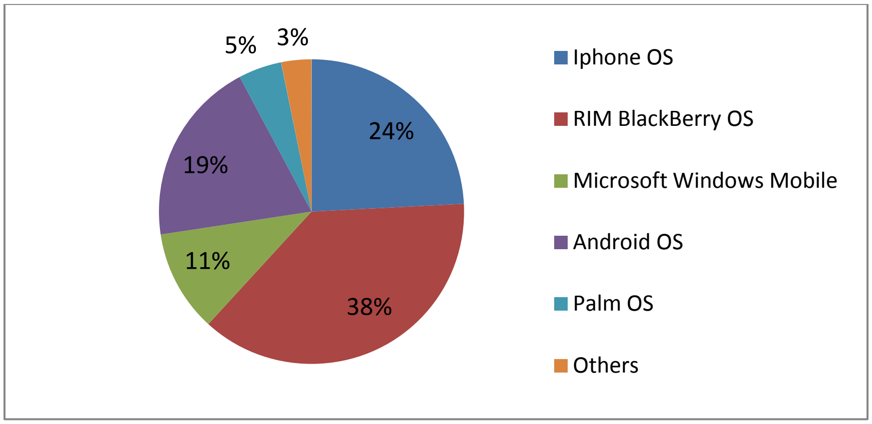

Figure 1: Smart phone Market Share (data source: [3])

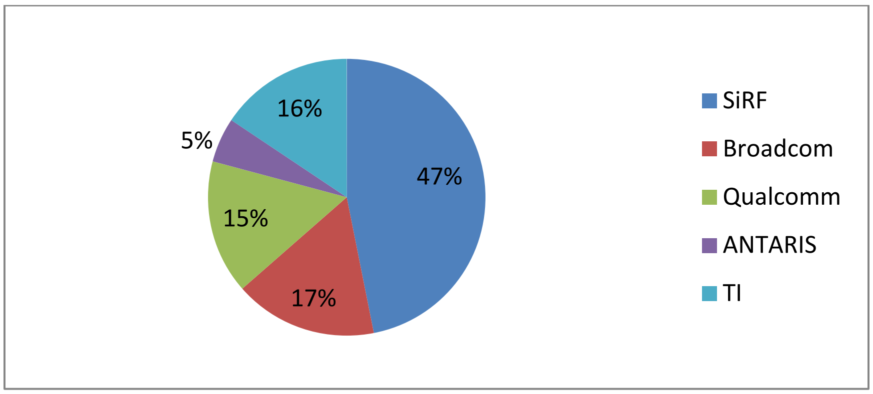

Figure 2: GPS chipsets share in cell-phone devices (data source: [3])

Chipset	Device Name	Device Type	OS
Broadcom Hammerhead II	iPod touch 4/iPad	Cell phone	iOS 4
Broadcom BCM4750	iPod touch 3G/s	Cell phone	MacOS
SiRFstarIII	iPod touch	Cell phone	MacOS
Qualcomm GPS-One	HTC Dream/G1	Cell phone	Android
SiRFstarIII	BlackBerry 8800	Cell phone	BlackBerry OS

Table 1: Information on chipsets, device types and operating systems of GPS devices (data source: [3])

Figure 1 shows that the RIM Blackberry has the largest market share with 38%, followed by the iPhone with 24% and Android-based phones with 19%. Figure 2 shows that SiRF GPS chipsets dominate almost half of the market with a share of 47% while Broadcom chipsets take 17% share followed by TI with 16%, Qualcomm with 15% and ANTARIS with 5%. The iPod touch and the HTC Dream/G1, an Android-based phone, use Broadcom and Qualcomm chipsets, respectively. Table 1 shows what GPS chipsets and operating systems the most popular devices use.

2 Related work

In [2], the authors established three measurement testing courses in open sky, young forest, and closed canopy settings within a conifer-dominated forest in western Oregon and rigorously tested the positional accuracy of six different GPS systems. They used six user-grade GPS receivers (SporTrak Map, GPSmap 76S, GPS V, Etrex Vista, Geko 301, Meridian Platinum) to take the measurements. They found that performance varied in some cases considerably. They concluded that users could expect positional accuracy within approximately 5 m of the real position in open sky settings, 7 m in young forest conditions, and 10 m under closed canopies.

In [4], the authors introduced various statistical methods for describing specifications for GPS receivers and commonly used accuracy measures.

Our measurements mainly focused on the performance of GPS in cell-phones and we selected three typical settings, that is open sky, heavy foliage and urban canyon, to take the measurements. We not only analyzed the positional accuracy, but also the time to first fix.

3 Application Development

In this section we discuss our efforts for developing the GPS application on the HTC Dream/G1 and the iPod touch.

3.1 Android phone

We set up and configured the necessary Android developing environment including installing Android Software Development Kit (SDK), Android Development Tools (ADT) Plug-in and Android Virtual Device (AVD) Manager. We implemented in Java an Android application for measuring location accuracy and tested it on the Android emulator and then the phone. As we can see in Figure 3 in our application latitude, longitude and time to first fix were shown on the screen and then recorded to files following the CSV format, convenient for analyzing data.

After the application is launched, the change of location can be monitored and latitude, longitude and time for updating location are shown on the screen. In the Android Application Programming Interface(API) the function LocationManager.requestLocationUpdates() registers for periodic updates of the user's current location from a location provider (GPS_PROVIDER). Once location information changes, another function onLocationChanged() will be called to respond to that change.

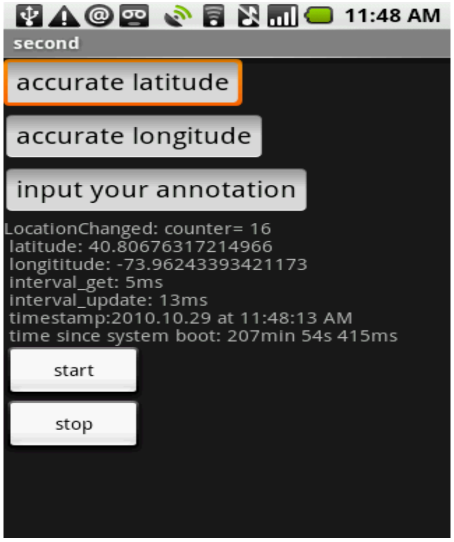

Figure 3: User interface

3.2 iPod touch

Figure 4 shows the application user interface for iPod touch. The integrated development environment (IDE) used to develop application on the iPod touch is Xcode and the programming language is Objective-C. The application for the iPod touch behaves the same way as that for the HTC Dream/G1. Measurements on the iPod touch are reserved for the future work.

Figure 4: iPod touch User Interface

3.3 Application Output

The application outputs data into CSV files. These files contain full-resolution coordinates, timestamp (time since epoch) and time to first fix which is defined in [6] as “a measure of the time required for a GPS receiver to acquire satellite signal and navigation data, and calculate a position solution”. Time to first fix depends on whether the device is in cold-start or warm-start mode. In our measurement, we turned the device off and rebooted it before starting the GPS measurement so that the device was in cold-start mode.

4 Measurements

We collected many data sets of device location including latitude, longitude, timestamp, and time to first fix on different locations representing three settings: open sky, heavy foliage and urban canyon. The purpose of the measurements is to compare the accuracy of location determination and time to first fix in the three settings mentioned above. In every location we set the interval between location updates to two seconds first and ten seconds later.

The phone we use is the HTC Dream/G1 running Android 1.6 Operating System [7]. It has a 528 MHz Qualcomm MSM7201A ARM11 processor with 192 MB of RAM and 256 MB of Flash memory.

A website(http://www.geocaching.com/) provides coordinates information of different locations with benchmarks. A benchmark is a point whose position is known to a high degree of accuracy and is normally marked in some way. In 2000, this website imported a snapshot of the ever-changing benchmark database from National Geodetic Survey (NGS), a federal agency within the US Department of Commerce. The NGS database contains all sorts of information about these benchmarks. We selected the measurement locations for the three settings among the ones listed in this website.

The first set of measurements was taken at noon on Dec 10th, 2010 with cloudy weather. The second set of measurements was taken at noon on Jan 15th, 2011 with sunny weather. The third set of measurements was taken in the evening on Dec 11th, 2010 with a clear sky.

For these sets of measurements the locations used belong to location set 1: Battery Place (N 40° 42.242 W 74° 01.057) chosen as the open sky setting, Riverside Park (N 40° 48.817 W 73° 57.567) chosen as the heavy foliage setting and Manhattan Roerich Museum Tower (N 40° 48.025 W 73° 58.265) chosen as the urban canyon setting.

A fourth set of measurements was taken at noon on Dec 11th with sunny weather. For the fourth set of measurements the locations used belong to location set 2: Prospect Street (N 40° 42.057 W 73° 59.358) chosen as the open sky setting, Morningside Park (N 40° 44.233 W 74° 00.317) chosen as the heavy foliage setting and Manhattan Mcgraw Hill (N 40° 48.025 W 73° 58.265) chosen as the urban canyon setting.

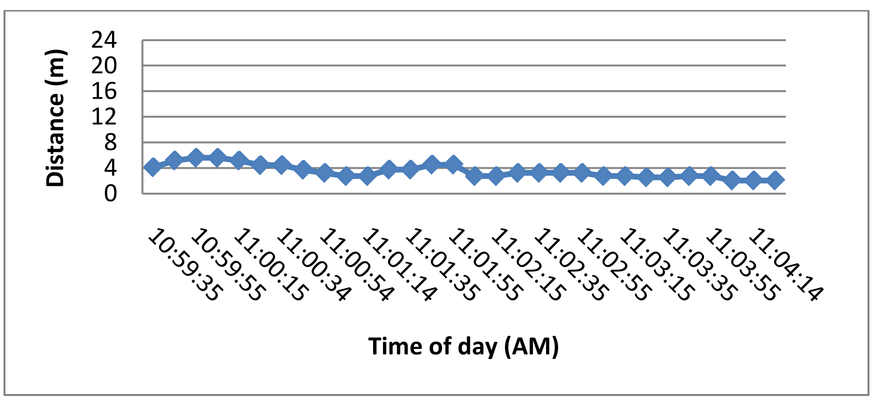

Figure 5: Position error in meters for an open sky setting: cloudy noon, Battery Place

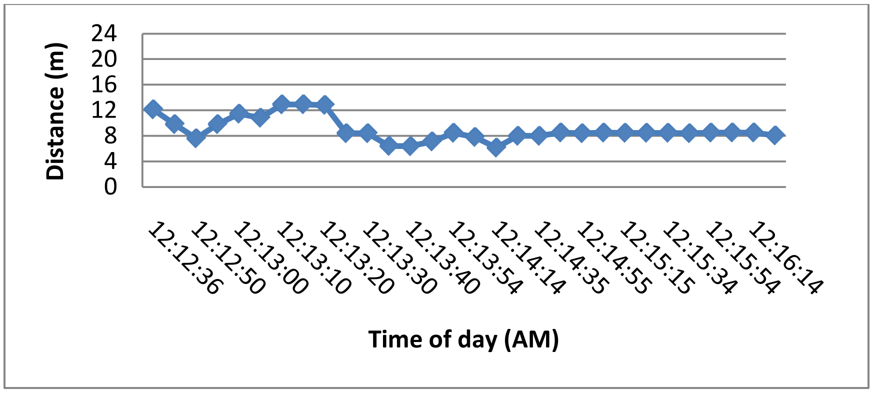

Figure 6: Position error in meters for a heavy foliage setting: cloudy noon, Riverside Park

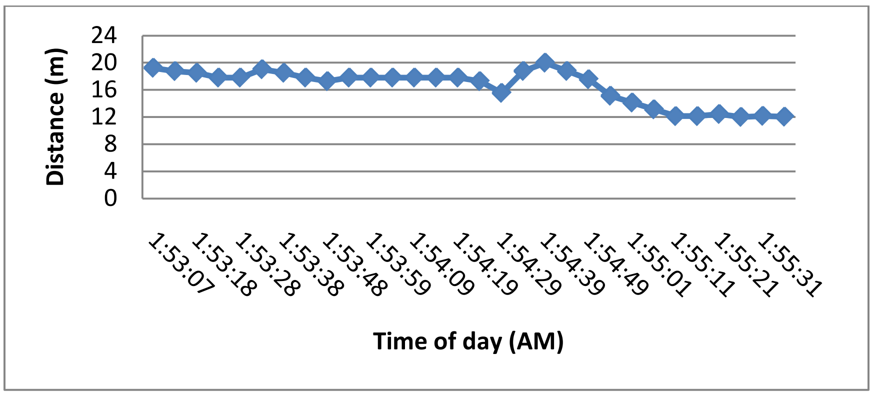

Figure 7: Position error in meters for an urban canyon setting: cloudy noon, Manhattan Roerich Museum Tower

Figures 5, 6 and 7 show the difference expressed in meters between the real position and measured positions for the three settings at noon with cloudy weather.

In the open sky setting, Figure 5 shows that the position error is about 4 meters for the first fix. The largest distance between the real position and the measured position is about 6 meters and the error converges towards a value of 2 meters after about 100 seconds.

In the heavy foliage setting, Figure 6 shows that the position error is about 12 meters for the first fix. The largest distance between the real position and the measured position is about 13 meters and the error converges towards a value of 8 meters after about 120 seconds.

In the urban canyon setting, Figure 7 shows that the position error is about 19 meters for the first fix. The largest distance between the real position and the measured position is about 20 meters and the error converges towards a value of 12 meters after about 130 seconds.

The open sky setting gives the best approximation of the real position for the first fix, the lowest position error and the error converges fastest because fewer obstacles can affect the signal of satellites. The heavy foliage setting gives the second best approximation of the real position for the first fix, the second lowest position error and the error converges second fastest. The urban canyon setting gives the worst approximation of the real position for the first fix, the worst position error and the error converges slowest in that the tall buildings may weaken or reflect the signal.

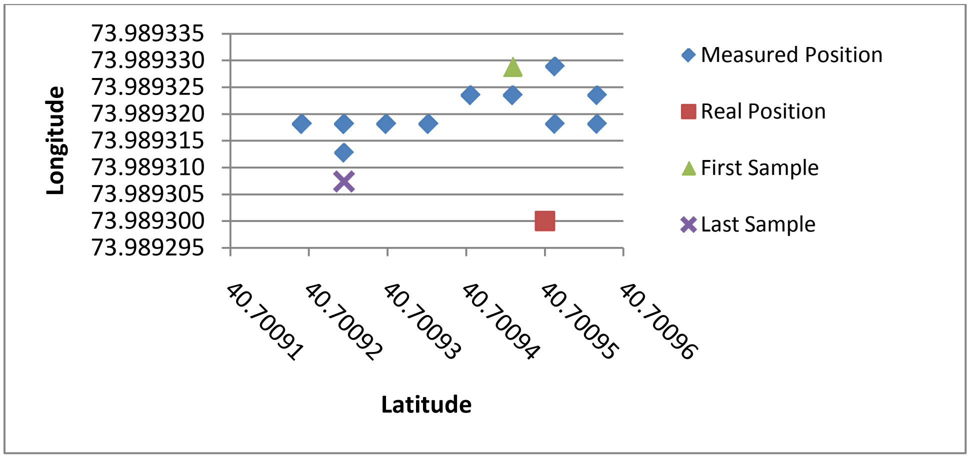

Figure 8: Measured positions distribution for an open sky setting: cloudy noon, Battery Place

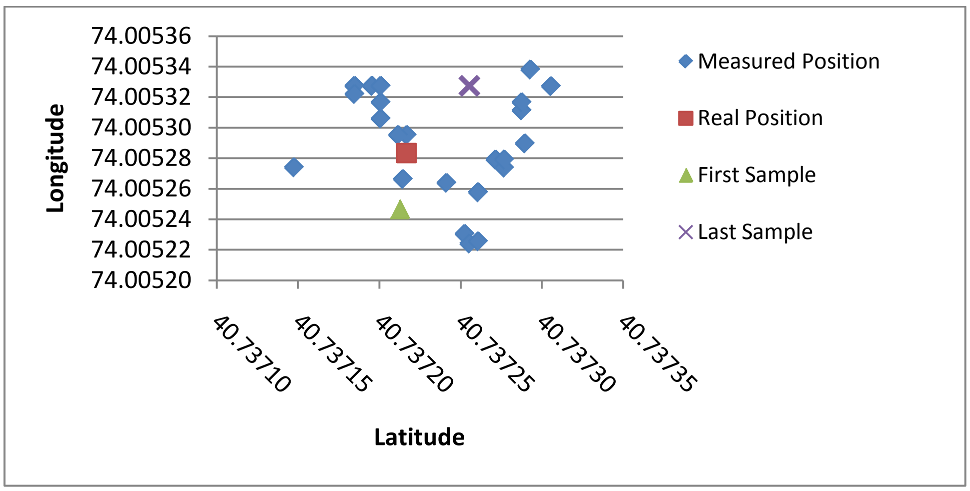

Figure 9: Measured positions distribution for a heavy foliage setting: cloudy noon, Riverside Park

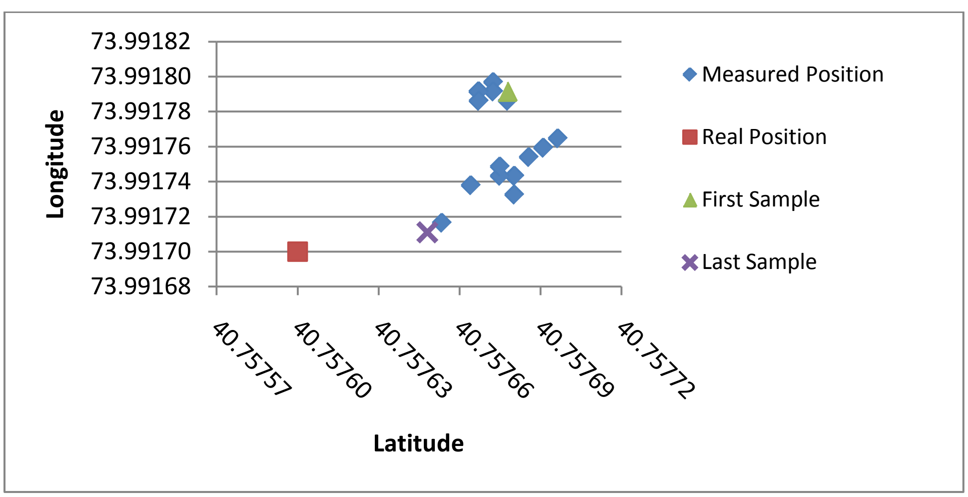

Figure 10: Measured positions distribution for an urban canyon setting: cloudy noon, Manhattan Roerich Museum Tower

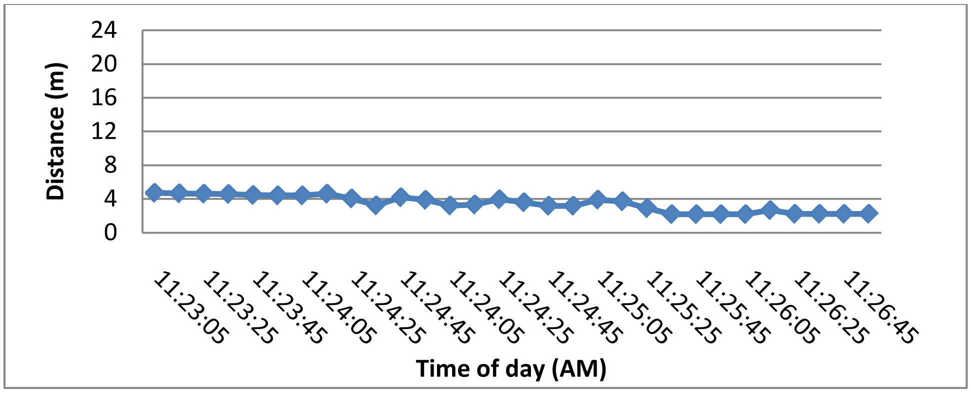

Figure 11: Position error in meters for an open sky setting: sunny noon, Battery Place

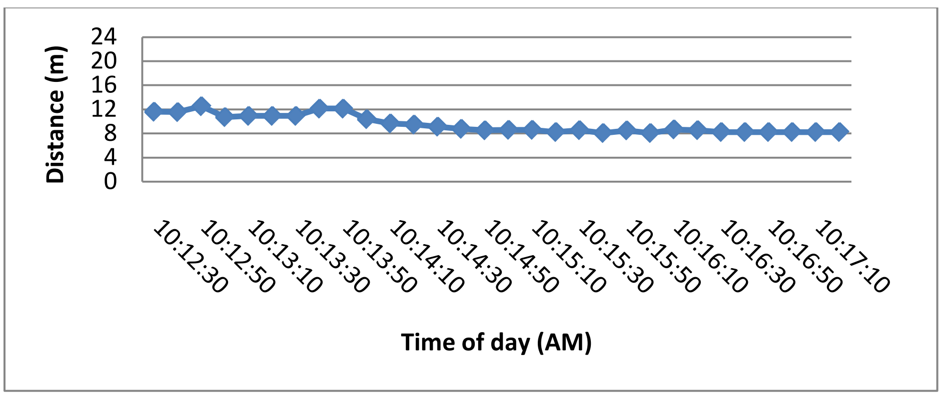

Figure 12: Position error in meters for a heavy foliage setting: sunny noon, Riverside Park

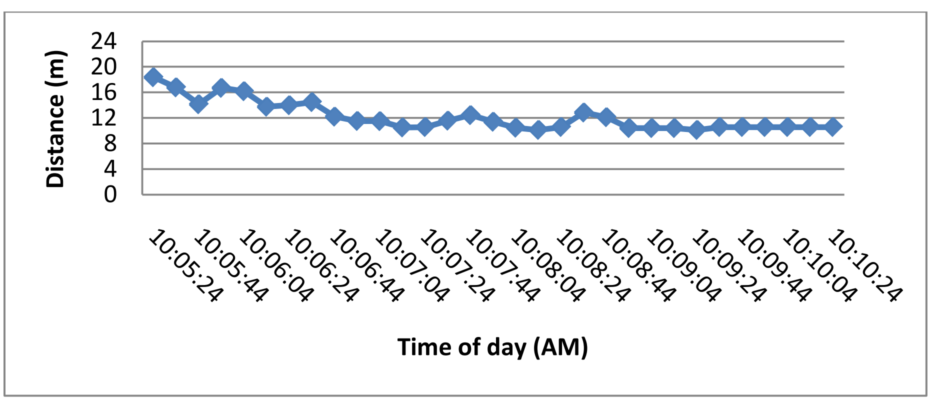

Figure 13: Position error in meters for an urban canyon setting: sunny noon, Manhattan Roerich Museum Tower

Figures 11, 12 and 13 show the difference expressed in meters between real position and measured positions for the three settings at noon with sunny cloudy.

For an open sky setting, Figure 11 shows that the position error is about 4.5 meters for the first fix. The largest distance between real position and measured position is about 4.5 meters and the error converges towards a value of 2 meters after about 120 seconds.

Figure 12 shows that in a heavy foliage setting the position error is about 12 meters for the first fix. The largest distance between the real position and the measured position is about 13 meters and the error converges towards a value of 8 meters after about 160 seconds.

Figure 13 shows that for an urban canyon setting position error is about 18 meters for the first fix. The largest distance between the real position and the measured position is about 18 meters and the error converges towards a value of 11 meters after about 200 seconds.

The open sky setting gives the best approximation of the real position for the first fix and the lowest position error. In this setting the error converges faster than in the other settings because fewer obstacles affect the signal of satellites. The heavy foliage setting gives the second best approximation of the real position for the first fix, the second lowest position error and the error converges second fastest. The urban canyon setting gives the worst approximation of the real position for the first fix, the worst position error and the error converges slowest in that the tall buildings may weaken or reflect the signal.

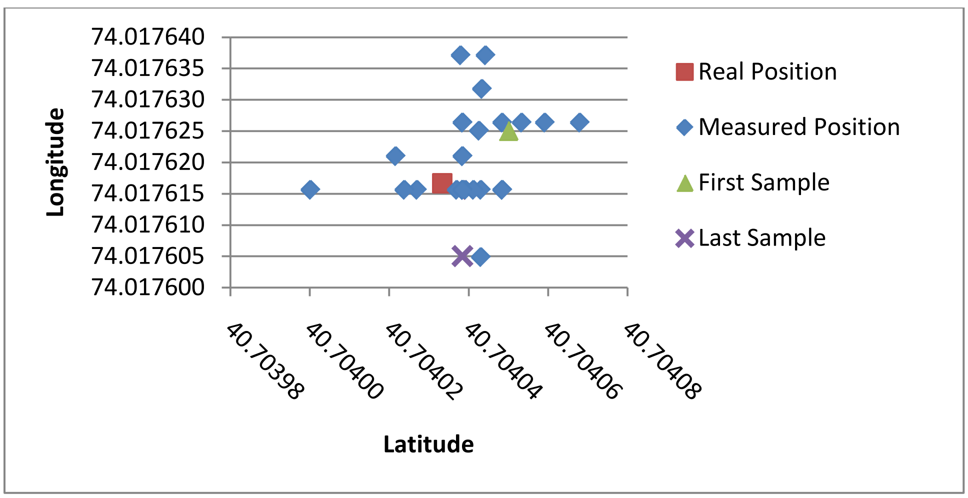

Figure 14: Measured positions distribution for an open sky setting: sunny noon, Battery Place

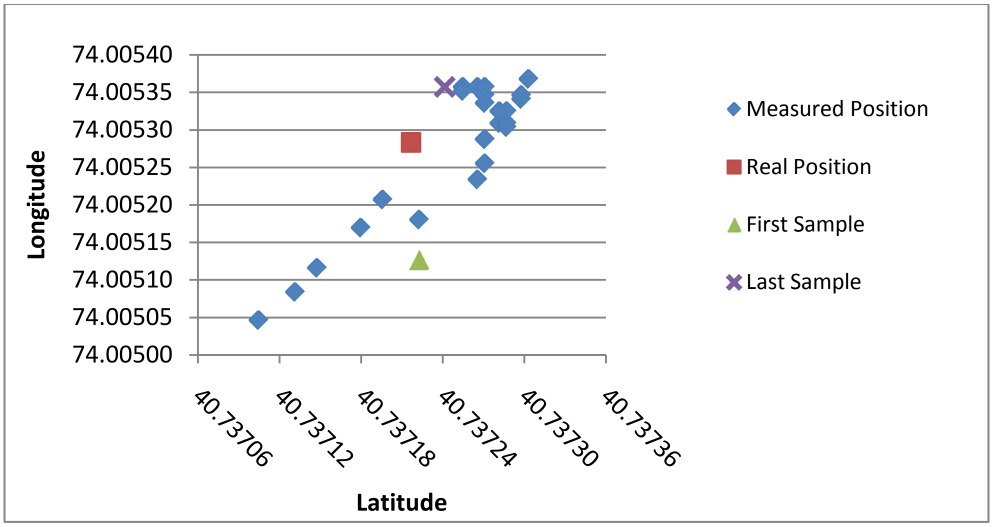

Figure 15: Measured positions distribution for a heavy foliage setting: sunny noon, Riverside Park

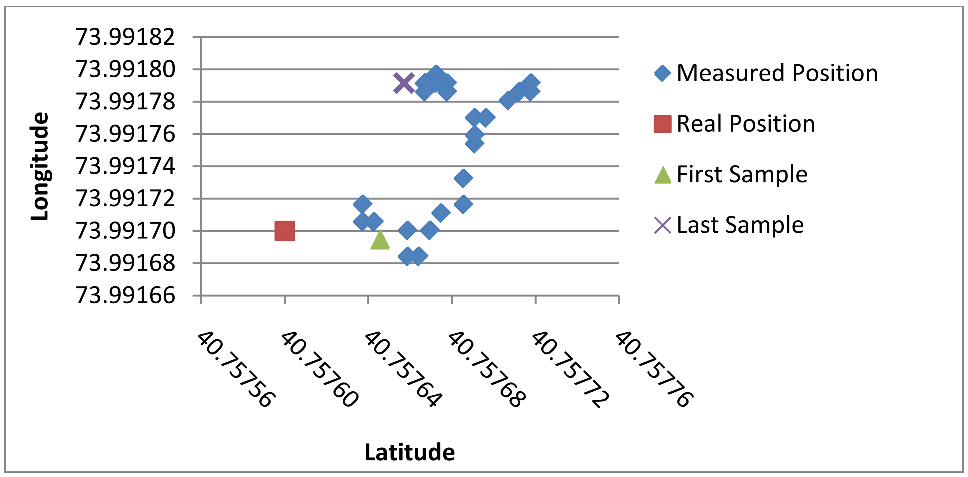

Figure 16: Measured positions distribution for an urban canyon setting: sunny noon, Manhattan Roerich Museum Tower

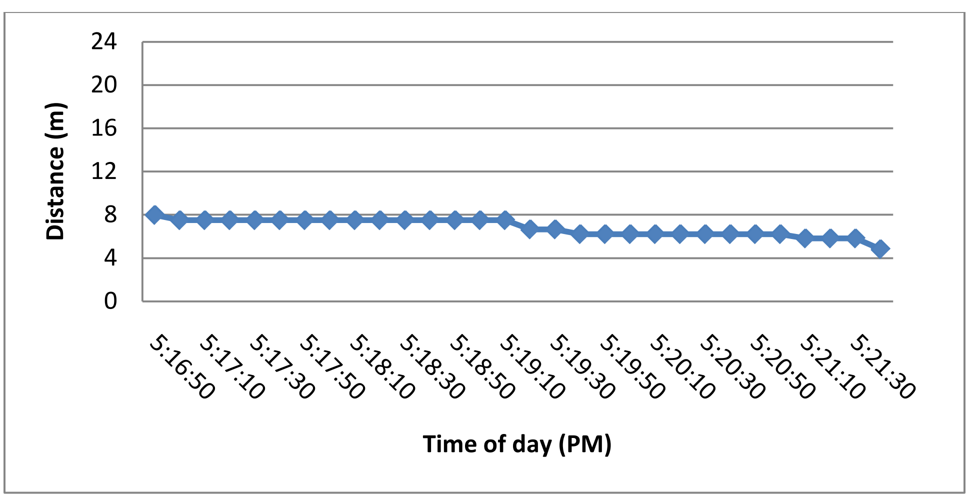

Figure 17: Position error in meters for an open sky setting: evening with a clear sky, Battery Place

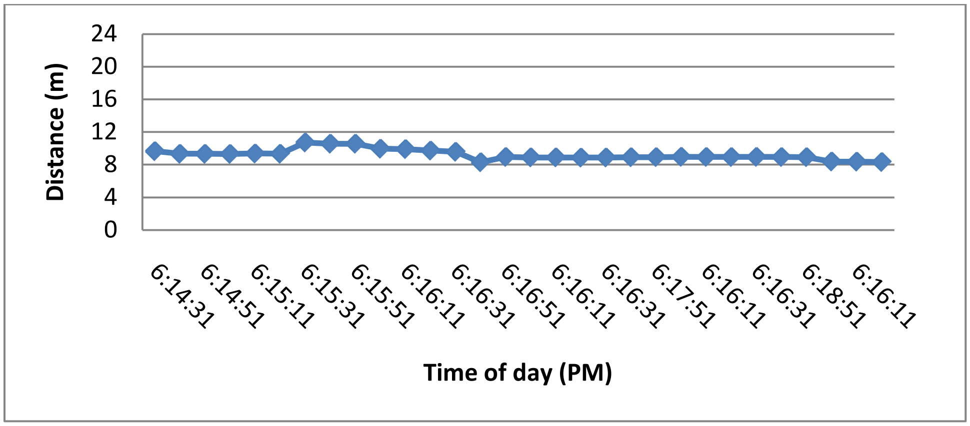

Figure 18: Position error in meters for a heavy foliage setting: evening with a clear sky, Riverside Park

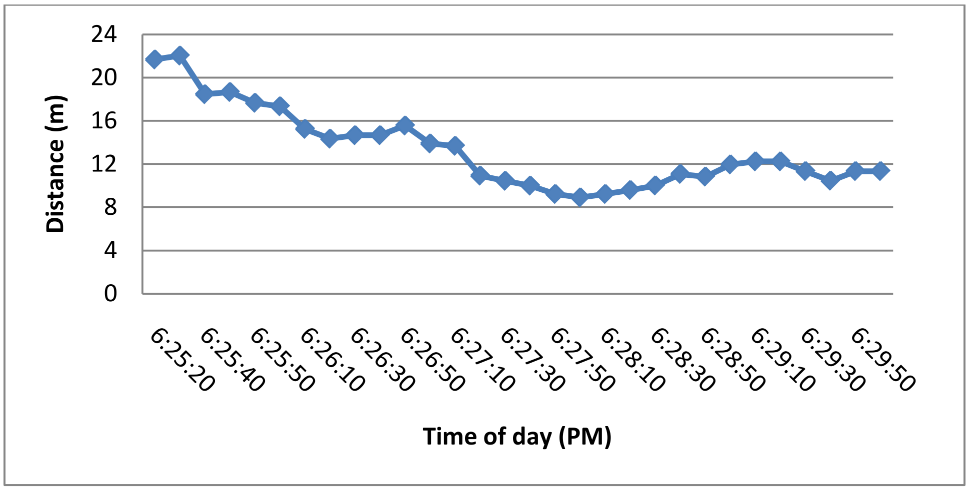

Figure 19: Position error in meters for an urban canyon setting: evening with a clear sky, Manhattan Roerich Museum Tower

Figures 17, 18 and 19 show the difference expressed in meters between the real position and measured positions for the three settings in the evening with a clear sky.

Figure 17 shows that in an open sky setting the position error is about 8 meters for the first fix. The largest distance between the real position and the measured position is about 8 meters and the error converges towards a value of 6 meters after about 130 seconds.

Figure 18 shows that in heavy foliage setting the position error is about 10 meters for the first fix. The largest distance between the real position and the measured position is about 11 meters and the error converges towards a value of 8 meters after about 140 seconds.

Figure 19 shows that in an urban canyon setting the position error is about 22 meters for the first fix. The largest distance between the real position and the measured position is about 22 meters and the error converges towards a value of 10 meters after about 180 seconds.

The open sky setting gives the best approximation of the real position for the first fix, the lowest position error and the error converges fastest because fewer obstacles can affect the signal of satellites. The heavy foliage setting gives the second best approximation of the real position for the first fix, the second lowest position error and the error converges second fastest. The urban canyon setting gives the worst approximation of the real position for the first fix, the worst position error and the error converges slowest in that the tall buildings can weaken and reflect the signal.

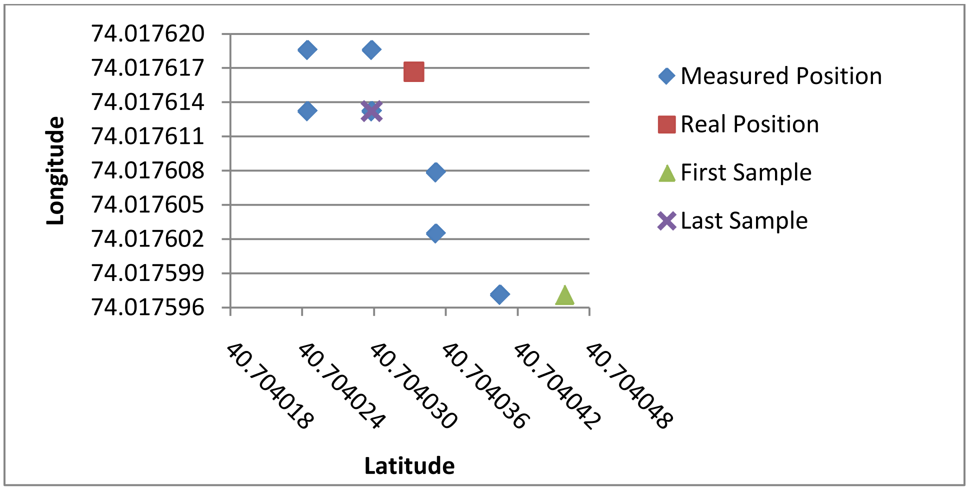

Figure 20: Measured positions distribution for an open sky setting: evening with a clear sky, Battery Place

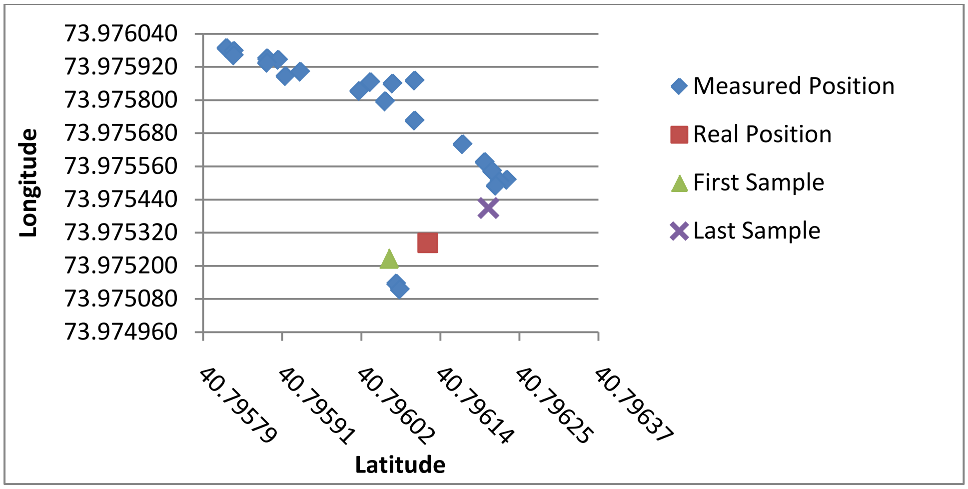

Figure 21: Measured positions distribution for a heavy foliage setting: evening with a clear sky, Riverside Park

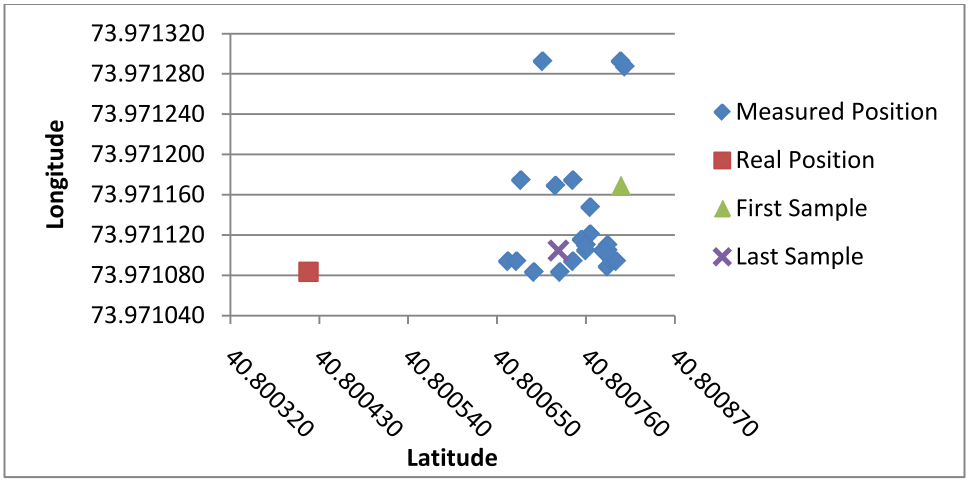

Figure 22: Measured position distribution for an urban canyon setting: evening with a clear sky, Manhattan Roerich Museum Tower

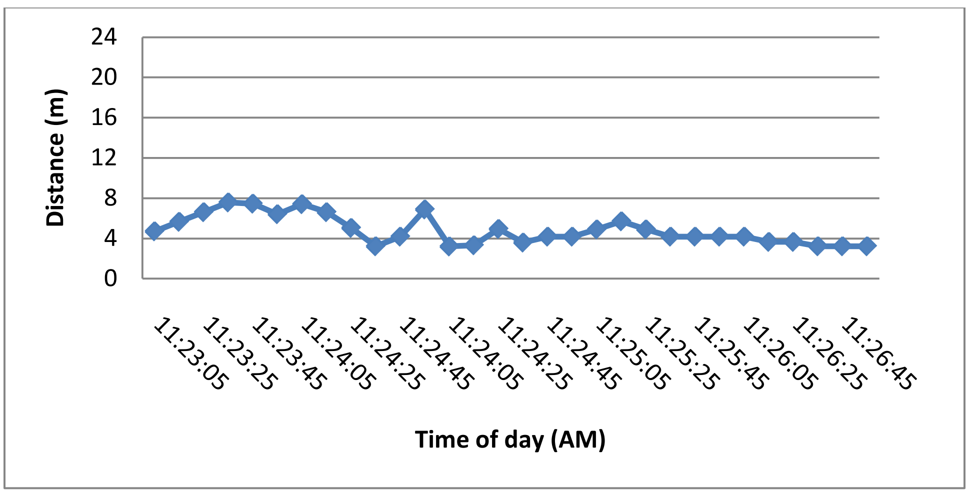

Figure 23: Position error in meters for an open sky setting: noon sunny, Prospect Street

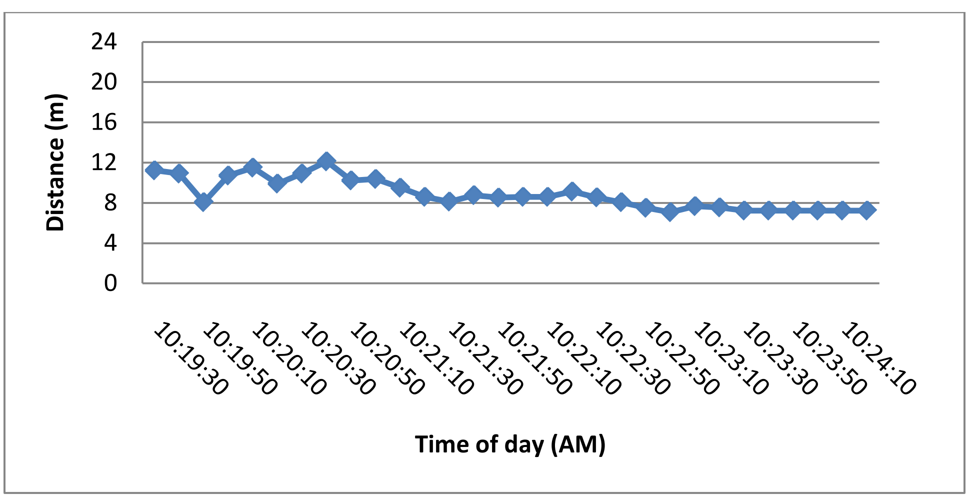

Figure 24: Position error in meters for a heavy foliage setting: noon sunny, Morningside Park

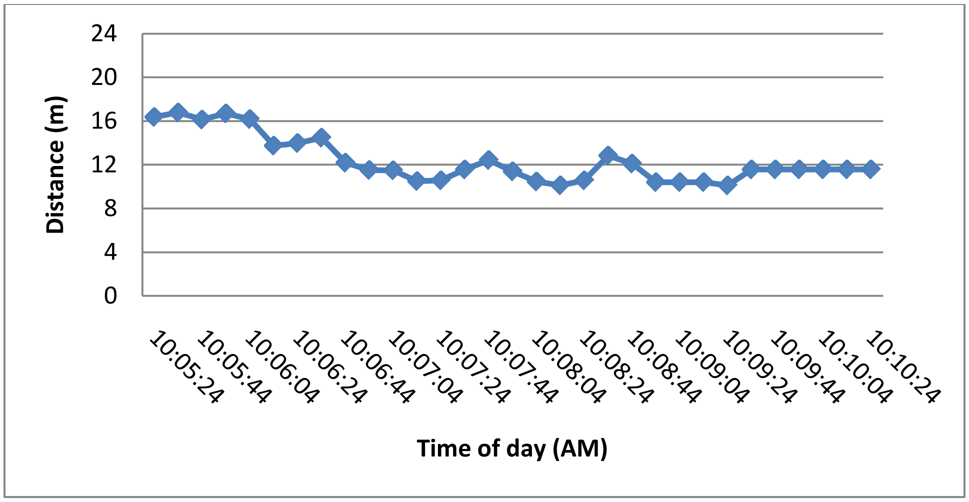

Figure 25: Position error in meters for an urban canyon setting: noon sunny, Manhattan Mcgraw Hill

Figures 23, 24 and 25 show the difference expressed in meters between real position and measured positions for the three settings at noon with sunny weather.

For the open sky setting, Figure 23 shows the position error is about 4 meters for the first fix. The largest distance between the real position and the measured position is about 8 meters and the error converges towards a value of 3 meters after about 120 seconds.

For the heavy foliage setting, Figure 24 shows the position error is about 8 meters for the first fix. The largest distance between the real position and the measured position is about 12 meters and the error converges towards a value of 7 meters after about 200 seconds.

For the urban canyon setting Figure 25 shows the position error is about 16 meters for the first fix. The largest distance between the real position and the measured position is about 17 meters and the error converges towards a value of 12 meters after about 240 seconds.

The open sky setting gives the best approximation of the real position for the first fix, the lowest position error and the error converges fastest because few obstacles can affect the signal of satellites. The heavy foliage setting gives the second best approximation of the real position for the first fix, the second lowest position error and the error converges second fastest. The urban canyon setting gives the worst approximation of the real position for the first fix, the worst position error and the error converges slowest in that the tall buildings can weaken and reflect the signal.

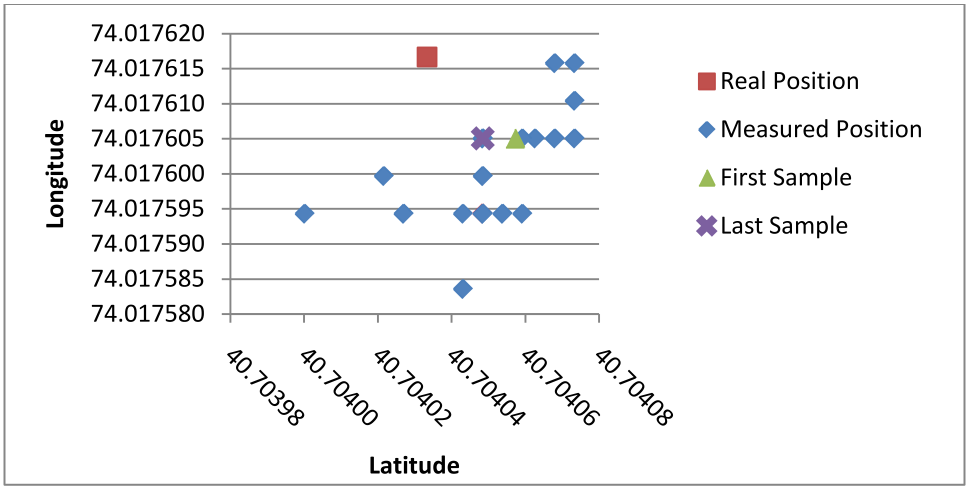

Figure 26: Measured positions distribution for an open sky setting: noon sunny, Prospect Street

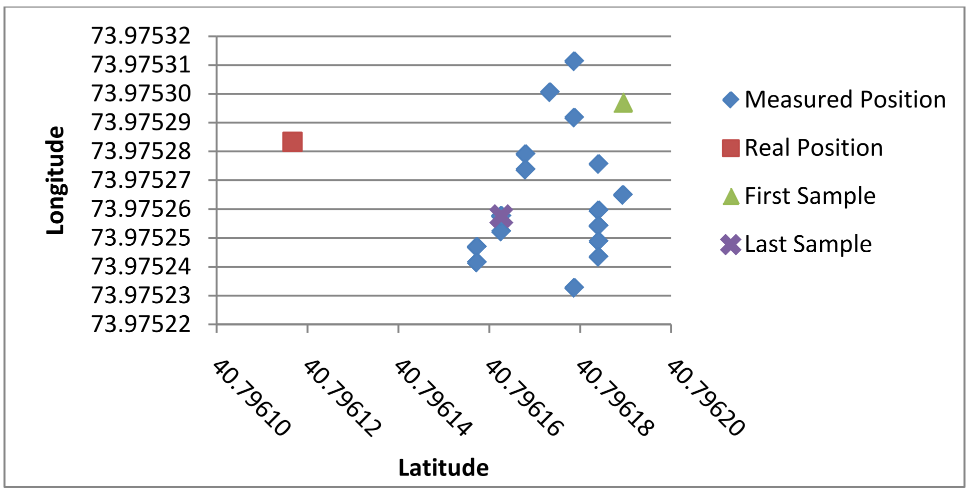

Figure 27: Measured positions distribution for a heavy foliage setting: noon sunny, Morningside Park

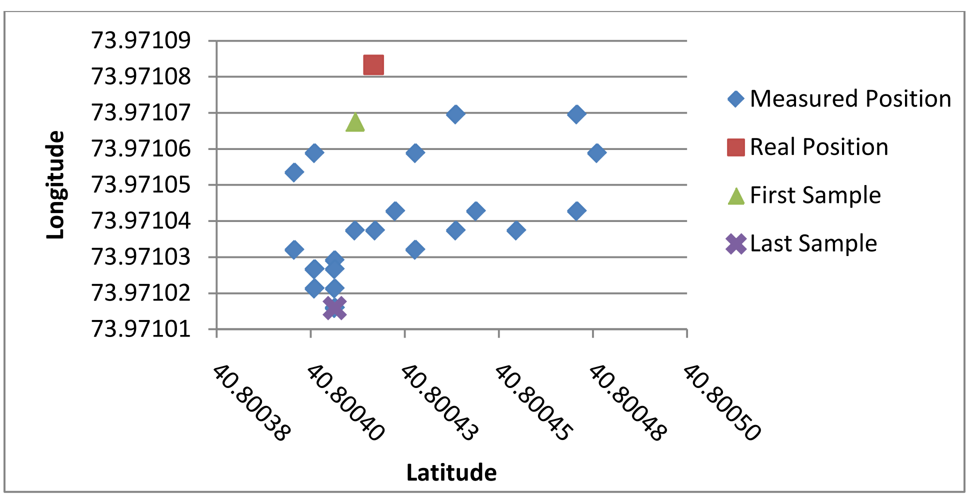

Figure 28: Measured positions distribution for an urban canyon setting: noon sunny, Manhattan Mcgraw Hill

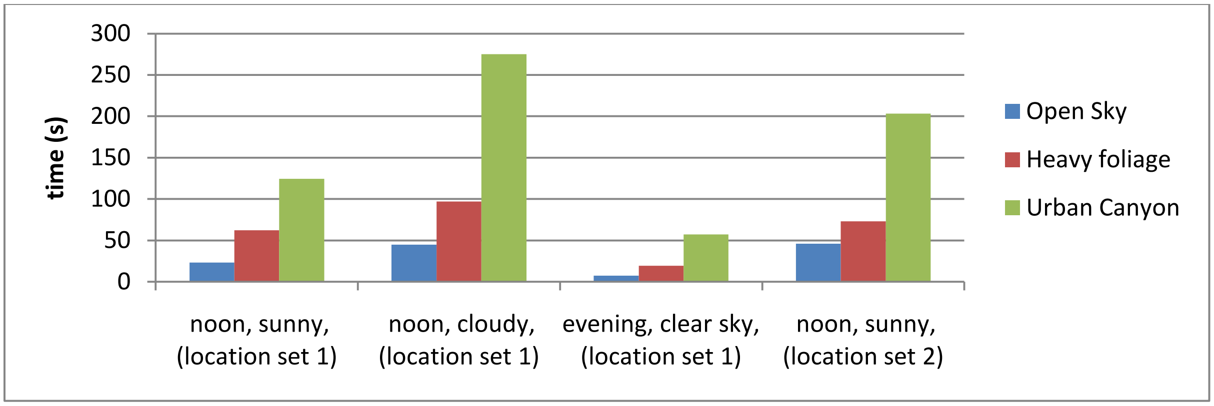

Figure 29: Time to first fix for different settings

Figure 29 shows that in location set 1 time to first fix in open sky is generally shorter than heavy foliage because it is easier to find satellites in the open sky setting without obstructions such as trees. Time to first fix in heavy foliage is shorter than that in urban canyon in that it is easier to find satellites in the heavy foliage setting where there are few tall buildings obstructing the view of sky. Time to first fix with sunny weather is generally shorter than that with cloudy weather, for it is easier to find satellites with sunny weather. Time to first fix in the evening is generally shorter than that at noon because it is easier to find satellites in the evening when the sky is clearer. In location set 2 the time to first fix is longer perhaps because it is harder to find satellites for GPS devices when doing the measurements in the locations of location set 2 where there are more obstructions.

5 Conclusions

The positional accuracy of GPS devices and time to first fix are major concerns when users choose GPS devices. Our goal was to test an Android-based phone to determine average positional errors and time to first fix respectively. We used several locations to represent three distinct settings. The website http://www.geocaching.com/ provides coordinates information of different locations with benchmarks. We selected the measurement locations as three settings among the ones listed in the website. A benchmark is a point whose position is known. This website imported a snapshot of the ever-changing benchmark database from National Geodetic Survey (NGS).

We searched for information about market share of chipsets and what GPS chipsets are in which devices in order to focus on the most popular chipsets and devices. The chipset in the Android HTC Dream/G1 is Qualcomm GPS-One. Then we developed an application for measurements on Android phones and iPod Touch. After that we took the measurements in different settings. The time of days and weather were also different. The final step was to do data processing and analysis.

We found location accuracy to be within approximately 2 meters of the real position in an open sky setting, within 8 meters in a heavy foliage setting, and within 12 meters in an urban canyon setting. On the other hand, the time to first fix in an open sky setting is shorter than that in a heavy foliage setting and an urban canyon setting. Time to first fix with sunny weather is generally shorter than that with cloudy weather and time to first fix in the evening is generally shorter than that at noon.

6 Future Work

We plan to use iPod touch to take the same measurements in the same locations, and then compare the results. Afterwards we will take similar measurements in new locations. For example we will take the measurements in the middle of an avenue, or the middle of a street as in these settings devices can see more sky that on the one side of an avenue or a street. Also tall buildings on an avenue or a street are located on the opposite side which may affect the GPS signal.

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